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Linear anionic polyacrylamide as an effective post-fire soil treatment: Understanding the chemistry and physical science

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Abstract: Controlling erosion, reestablishing vegetation, and overcoming the negative effects of hydrophobic soils has long been a challenge following catastrophic wildfire on forested lands and rangelands. A three-year controlled study was recently completed to compare polyacrylamide soil treatment to the traditional cover method using agricultural straw on high severity burned soils of the Red Bull Fire, which burned through the Uinta National Forest near Provo, Utah, in July and August of 2004. Weed free, recycled paper pellets containing polyacrylamide were found to be an effective Burn Area Emergency Rehabilitation treatment option on clay rich soils containing divalent cations (i.e., Ca^{2+}) within the soil matrix. This study showed aerial application of the granular polyacrylamide pellets resulted in an even distribution of the polymer-based product on the soil surface. Through water activation, a blend of water-soluble linear anionic polyacrylamide copolymers are slowly released, which bind with the soil particles, structurally stabilizing the soil. When compared to agricultural straw, polyacrylamide results show improved revegetation, reduced soil hydrophobicity, and reduced soil erosion.

Key words: Burn Area Emergency Rehabilitation—erosion—hydrophobic—polyacrylamide (PAM)—post-fire soil treatment—revegetation

A comprehensive three-year controlled study was recently completed to compare the use of PAM to the traditional, agricultural straw cover method on high burn severity impacted soils in the Uinta National Forest of Utah. This paper will present the collected data for this study and show the results for soil movement (erosion), soil hydrophobicity, and vegetation cover.

Preventing negative post-fire soil and watershed effects associated with catastrophic wildfires has been a challenge to Burn Area Emergency Rehabilitation teams. Burn Area Emergency Rehabilitation (BAER) deals with emergency risk management to post wildfire conditions based on values at risk. Common assessed post-fire values at risk include human life and property, degradation of soil productivity, loss of water quality, and loss of aquatic species habitats. High severity wildfire destroys the natural protection of the soil and leaves the soil and watershed vulnerable to large-scale erosion, flooding, debris flows, and mudflows from subsequent storms (Neary et al. 2005; DeBano et al. 1998). Shrubs, forbs, grasses, and organic litter decrease the energy of raindrop impact during severe rain storms, while plant roots stabilize the soil structure. These effects help minimize erosion, giving rainwater time to infiltrate into the soil. Thus, erosion control and rapid revegetation are of prime importance to minimizing the negative effects of wildfires (Davis and Holbeck 2001).

A soil can become more water repellent (hydrophobic) due to a wildfire. Increased fire intensity and burn time promotes the formation of water-repellent layers (hydrophobicity) at or near the soil surface and destroys the soil structure. Waxes released from volatilized organic matter during a wildfire move downward into the soil and condense around individual soil particles to form a water-repellent layer. Wax penetration into the soil may be a few millimeters to several centimeters below the surface, and the resulting water impervious barrier may be several centimeters thick. During rainstorm events, hydrophobic soils inhibit water infiltration, increase runoff, and detach surface soil particles, all of which increase flooding, erosion, sediment transport, and sedimentation (Davis and Holbeck 2001). Breaking up the hydrophobic layers and reestablishing soil structure stability are important to increase water infiltration and decrease soil erosion.

Post-fire treatments are designed to minimize risk of flooding and soil erosion through physical controls. Common risk-reduction treatments include large scale seeding, contour raking and tree-fall, log erosion barriers, hydromulch, and straw mulch. However, these treatments have met with varying degrees of success (Robichaud et al. 2000). During the first year following fire, straw mulch and contour-felled log barriers can reduce soil erosion rates up to 80%, while hydromulch and grass seeding have little to no effect (Robichaud and Elliot 2006). Treatment effectiveness is limited by rainfall intensity. Providing ground cover, such as straw and hydromulching, was critical to reducing hillslope and rill erosion on three separate wildfires in ponderosa pine forests in the Colorado Front Range. Seeding did not significantly increase percent cover or reduce sediment yields in these fires (Rough et al. 2004). Burn severity and rainfall intensity, however, decrease treatment effectiveness while significantly increasing the risk for flooding, debris, and mudflows (Robichaud and Elliot 2006; Pietraszek 2006; Moody and Martin 2001).

Polyacrylamide (PAM) polymers have been used to reduce soil erosion. The USDA and other research institutions have shown that the use of PAM can control soil erosion, increase water infiltration, and improve vegetation growth on irrigated agricultural lands (Bjorneberg et al. 2003; Entry et al. 2002; Lentz and Bjorneberg 2003; Yu et al. 2003; Lentz and Sojka 1994; Bjorneberg et

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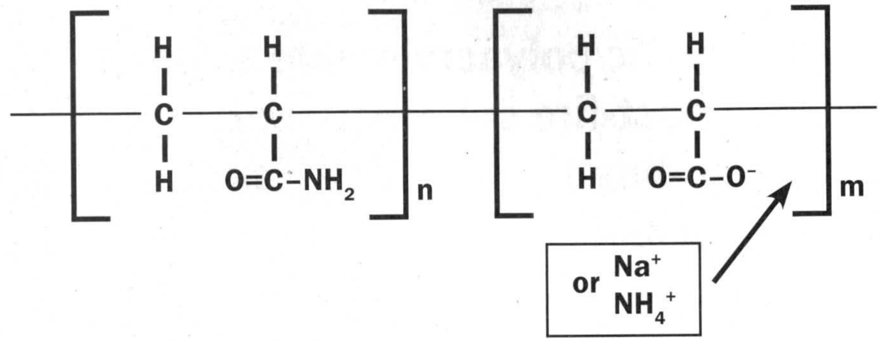
Figure 1
Repeating monomer units (represented by the lowercase n and m) in an anionic-linear polyacrylamide polymer are shown. Aqueous dissociation of Na^+ or NH_4^+ ions provide negative charge sites on the copolymer macromolecule. Typically, there are greater than 150,000 monomer units per molecule with molecular weight ranging from 12 to 20 Mg mol^{-1} and 20% to 30% anionic charge density.



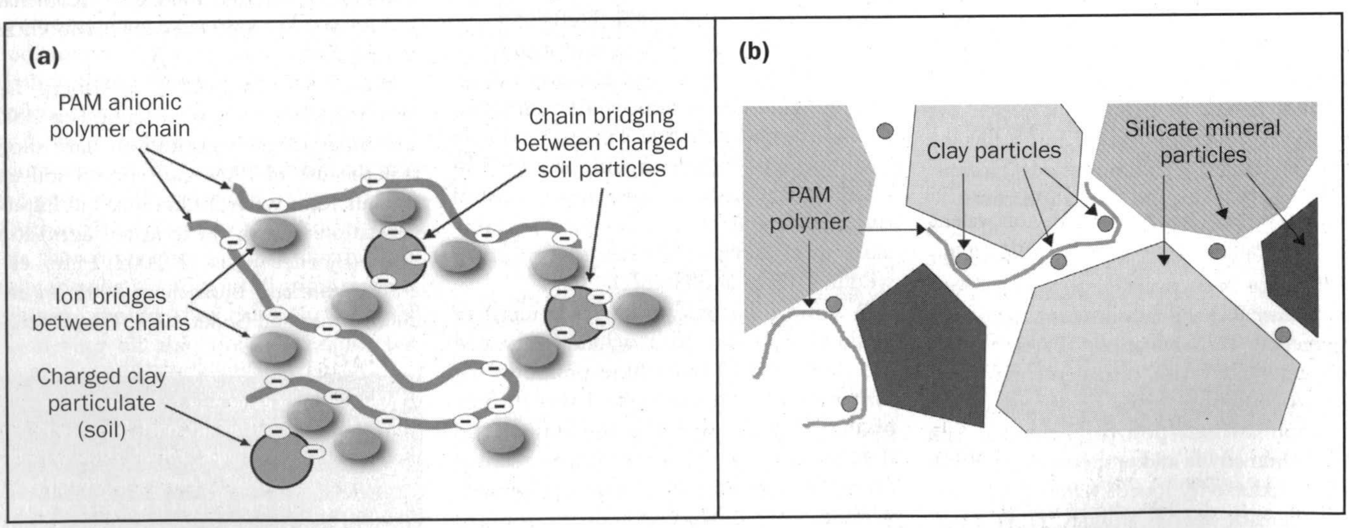
al. 2003). The addition of PAM to straw-mulch applications in furrow irrigation virtually eliminated runoff soil losses (Lentz and Bjorneberg 2003). For nonirrigated land, PAM is added to the soil surface either as a dry granular material or as a solution spray. Under these conditions, PAM increased the water infiltration rate in a silty loam and sandy clay by an order of magnitude while reducing runoff several fold. Spreading gypsum on the soil surface in addition to PAM application increased the infiltration rate even more (Yu et al. 2003).

The effectiveness of PAM depends on the clay and calcium content of the soil as well as the molecular weight and charge density of the polymer (Vacher et al. 2003). PAM works through an ionic attraction, which binds clay soil particles together when the concentration of electrolytes in the soil solution exceeds the flocculation value of the clay. Polyacrylamide and PAM plus gypsum treatments reduce both runoff and sediment loss on 32% to 45% slopes using simulated rainfall conditions (Vacher et al. 2003). Sandy loam soils derived from coarse grained igneous bedrock treated with PAM without gypsum amendments do not show any increased infiltration rate (Trout and Ajwa 2001).

Studies have shown that PAM applied to sandy loam soils decreases water infiltration. This effect is likely attributed to an increase in viscosity of the soil-water-PAM solution, which seals the interstitial soil pores (Ajwa and Trout 2006). These results can explain why PAM treatments to the mostly granitic sands of the Hayman and Schoonover fires had no significant reduction in sediment yields (Rough et al. 2004).

Polyacrylamide Soil Chemistry. Polyacrylamide (PAM) is a generic term that covers a broad class of chemical compounds which include hundreds of polymers with differing functional groups and chain lengths. A simplified view of a PAM polymer $(-CH_2CHCONH_2-)_n$ is shown in figure 1. The acrylamide subunits can be linear straight-chained or cross-linked. The cross-linked forms are highly water-absorbent, forming a soft gel used in

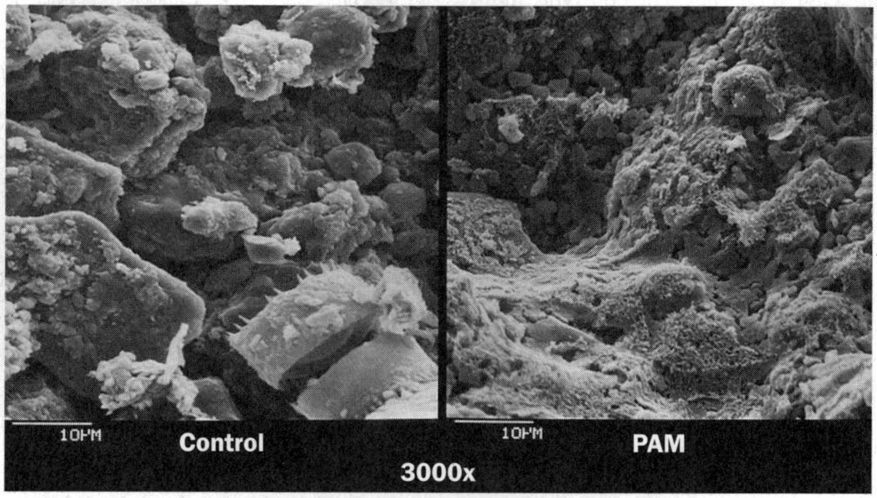
Figure 2
Interactions of anionic-linear polyacrylamide (PAM) molecules with charged soil clay particles are shown in (a). The small hydrated calcium ion radius shrinks the electrical double layer surrounding the soil particles. They then bridge the anionic soil surfaces and PAM molecules, enabling flocculation. Polyacrylamide applied to sand-based soils decrease infiltration, which is likely due to increased viscosity of soil solution resulting from the PAM molecules interacting with the clay fraction that seals the interstitial soil pores as shown in (b). The PAM treatment of sand based soils may result in physical entrapment of sand particles and weak surface interactions.



Note: part a is adapted from Orts et al. 2002.

Figure 3

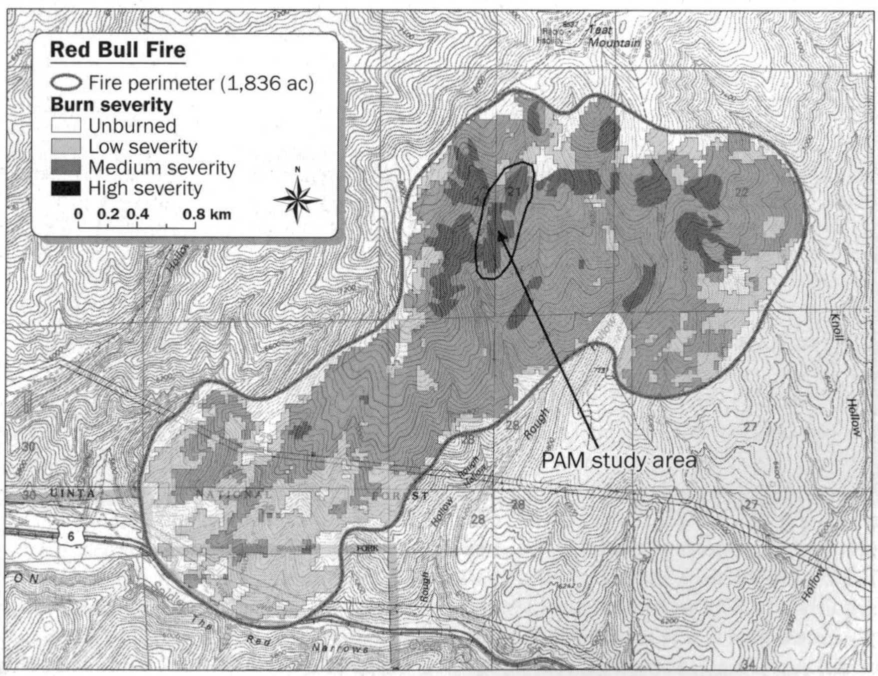
Scanning electron photograph of a clay soil without polyacrylamide (control) and clay soil treated with polyacrylamide. Polyacrylamide stabilizes the soil surface structure and improves soil-pore continuity (Entry et al. 2002).



Note: This photograph is from Entry et al. 2002.

Figure 4

The polyacrylamide study area is located in a high burn severity area of the Red Bull Fire area.



such applications as the manufacturing of soft contact lenses. The linear straight-chain forms are used as industrial flocculents for separating solids from aqueous suspensions.

Anionic water-soluble forms of polyacrylamide are frequently used as soil conditioners to control erosion on farmland, construction sites, and in mine land reclamation. These PAM formulations consist of linear polymer chains, which are not gel forming and are not super water absorbent. Along the charged copolymer chain, roughly 20% to 30% of the acrylamide chain segments are replaced by an acrylic acid group containing sodium or ammonium ions as shown in figure 1. Typically, these anionic PAM polymers have more than 150,000 monomer units with high molecular weight (12×10^6 to 15×10^6 g mol^{-1}) and moderate anionic charge density (20% to 30% hydrolysis) (Yu et al. 2003; Entry et al. 2002; Orts et al. 2002).

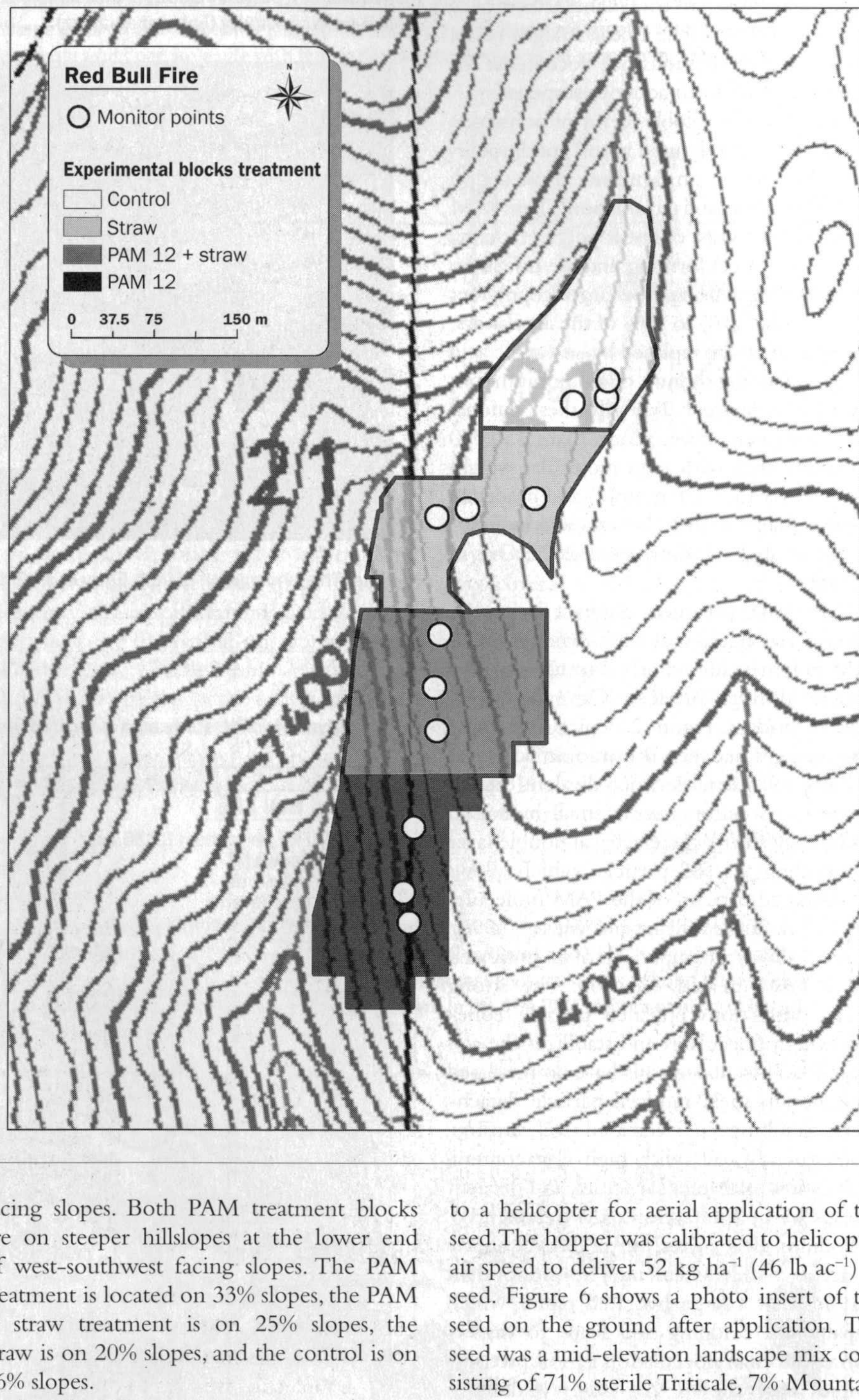
The PAM polymers interact primarily with the clay fraction of a soil. Anionic-linear PAM polymers are adsorbed to the soil clay particles through divalent (Ca^{2+} and Mg^{2+}) cationic bridges. Figure 2 depicts these cationic bridges between the anionic polymers and clay soil particles. Since divalent cations in the soil solution have a small hydration radius, they shrink the electrical double layer surrounding the soil particles which allows for strong adsorption of the PAM molecules (Orts et al. 2001; Wallace and Wallace 1996). Figure 3 shows a comparison of an untreated and a PAM treated clay soil. The strong surface attractions enhance particle cohesion which flocculates and stabilizes the soil structure. Flocculated soils have an increased resistance to shear-induced particle detachment, resulting in decreased soil erosion. Consequently, soils with high clay content, high cation exchange capacities, and divalent cations are best suited for PAM treatments.

Sodium electrolytes impair PAM's ability to act as a soil flocculent. The monovalent Na^+ ion has a large hydrated radius which impairs ion bridging and leads to dispersion rather than flocculation of soil particles. Studies have shown that water infiltration actually decreases for PAM-treated soils with high sodium adsorption ratios (Lentz and Sojka 1996). However, soils low in soluble divalent electrolytes can be successfully amended by applying gypsum as a calcium supplement to the PAM mixture (Yu et al. 2003; Flanagan et al. 2002a, 2002b; Entry et al. 2002). Soils treated with inorganic calcium supplements are less sensitive to pH variations and can therefore be used for treating a greater variety of soil types (Petersen et al. 2008).

Sandy based soils having low clay content (low cation exchange capacities) do not respond favorably to PAM addition (Trout and Ajwa 2001; Ajwa and Trout 2006). Figure 2 illustrates how PAM cannot bind sand particles together and may actually decrease water infiltration in a sandy soil by sealing off the interstitial pores.

Figure 5

Treatment map showing treatment blocks and sampling locations.



The amount of PAM and added gypsum need to be adjusted to account for varying soil/water properties. The soil type, molecular weight of the PAM polymer, and the soluble ion concentration in the soil solution are critical for improving the physical properties of the soil against raindrop impact and soil-particle dislodgement. Sediment reduction increases with the increasing molecular weight of anionic PAM (approximately 18% charge density). High molecular weight PAM (12×10^6 to 15×10^6 g mol^{-1}) improves soil structure in the top 1 to 5 mm (0.04 to 0.2 in) of soil. For soils having low ionic strength, significant reductions in sediment occur only when an outside source of soluble salts are used with the PAM application. For both low and high ionic-strength soils, divalent cation salts are significantly more effective than monovalent sodium salts (Orts et al. 2007).

Materials and Methods

This study was undertaken to compare the use of PAM to the traditional, agricultural straw cover method on high burn severity impacted soils in the Uinta National Forest of Utah. The study area was located within the burn perimeter area of the Red Bull Fire shown in figure 4. The Red Bull Fire burned on the Uinta National Forest near Provo, Utah, in July and August of 2004, and resulted in 67 ha (165 ac) of "high burn severity" across significant sloped areas that required the use of traditional Burn Area Emergency Rehabilitation (BAER) treatments of straw-mulching and seeding to prevent erosion, encourage re-vegetation, and to overcome the effects of fire-induced hydrophobic soils. Of the 67 ha, 8 ha (21 ac) were experimentally treated to test and compare treatment effectiveness of PAM and agricultural straw mulch. Using a factorial design, four experimental treatments were blocked on PAM, PAM + straw, straw, and an untreated control. The entire 67 ha were seeded, including all experimental blocks. The measured variables were (1) soil movement (erosion), (2) soil hydrophobicity, (3) vegetation cover, and (4) bare ground. All blocks were sampled in triplicate for each of these variables once a year for three years. Figure 5 shows the placement of the experiment treatment blocks and sample points within each block.

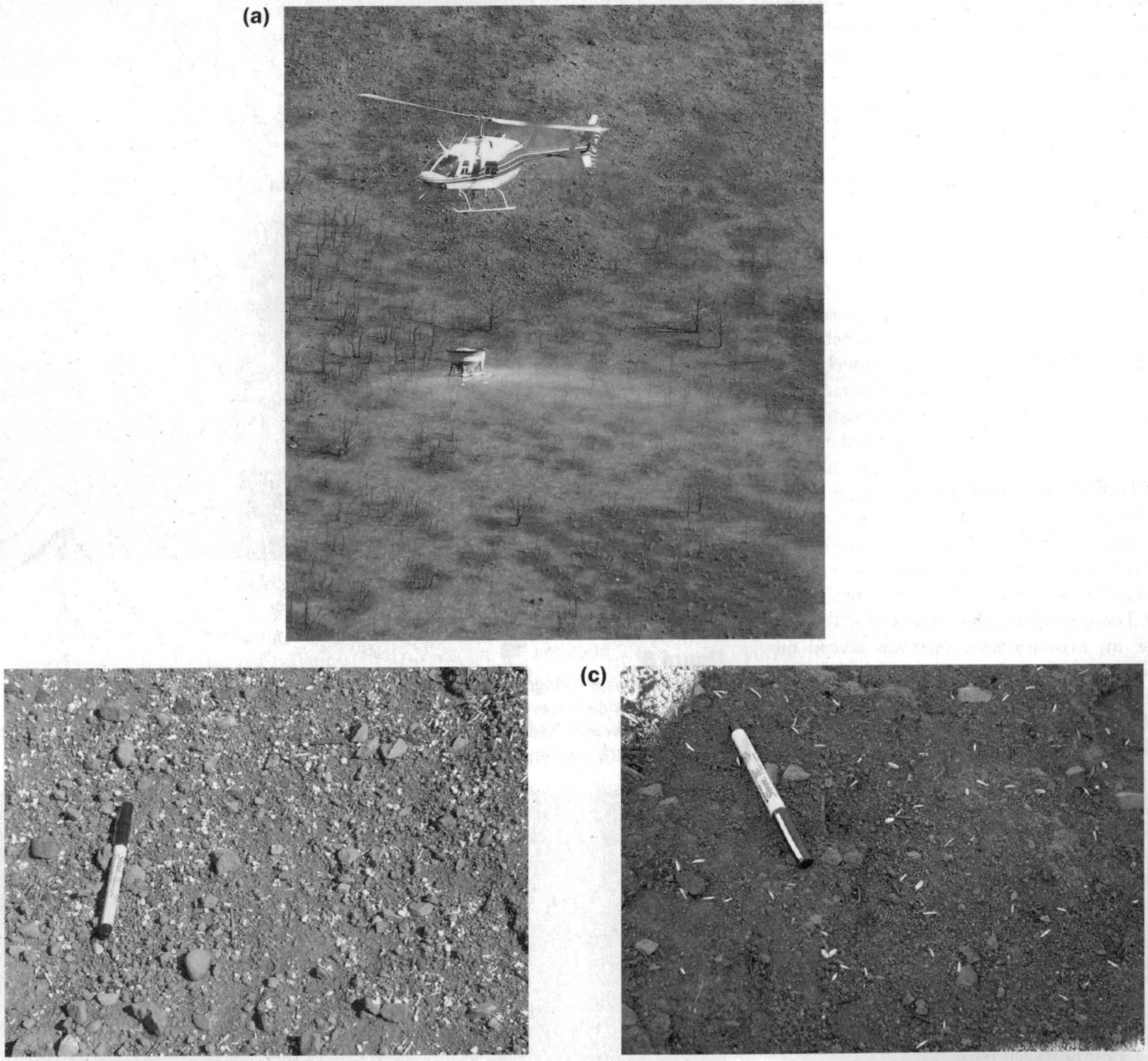
Treatment blocks were placed adjacent to each other on west and west-southwest facing slopes. Both PAM treatment blocks are on steeper hillslopes at the lower end of west-southwest facing slopes. The PAM treatment is located on 33% slopes, the PAM + straw treatment is on 25% slopes, the straw is on 20% slopes, and the control is on 16% slopes.

Applying Treatments. Treatment blocks were sized large enough for aerial application of the treatments by helicopter. Aerial seeding was first performed, then PAM application, and finally the agricultural straw. Seeding was accomplished by first loading approximately 900 kg (1 tn) of seed into a seed hopper, and then tethering the hopper to a helicopter for aerial application of the seed. The hopper was calibrated to helicopter air speed to deliver 52 kg ha^{-1} (46 lb ac^{-1}) of seed. Figure 6 shows a photo insert of the seed on the ground after application. The seed was a mid-elevation landscape mix consisting of 71% sterile Triticale, 7% Mountain Brome, 7% Slender Wheatgrass, 6% Sandberg Bluegrass, 7% Thickspike Wheatgrass, and 2% Bluebunch Wheatgrass.

A commercially available PAM product, PAM-12 with Advanced Soil Technology (AST) manufactured by ENCAP, LLC, was used for all polyacrlyamide soil treatments. The AST is a delivery system consisting of

Figure 6
(a) A seed hopper holding 900 kg of seed or PAM-12 pellets was tethered to a helicopter for aerial application. Prior to applying the products, the seed hopper was calibrated to the helicopter air speed for accurate ground application rates of each product. (b) PAM-12 pellets were applied at 670 kg ha^{-1}. Since 1.2% of the pellets are active polyacrylamide (PAM), the actual PAM application was 670 kg ha^{-1} × 1.2% = 8 kg ha^{-1}. (c) Seed coverage was 52 kg ha^{-1}.

(a) (b) (c)



a granular pellet material made of recycled paper that is impregnated with a mixture of water-soluble linear copolymers of different molecular weights (figure 7). Therefore, the pellets are water activated to give time release of different molecular weight PAM polymers. The pellets are also weed free. Overall, the PAM-12 recycled-paper pellets contain 1.2% polyacrylamide. The formulation for PAM-12 and AST is proprietary information. However, a wide range of differing molecular weight anionic PAM polymers were used in the manufacturing process; the average molecular weight of polymers used is 18×10^6 g mol^{-1}. The paper granules act as a carrier for the polyacrylamide, and are water activated to give a time release of different molecular weight polyacrylamide polymers. The PAM-12 product was delivered in 23 kg (50 lb) bags, which were loaded into the seed-hopper that held approximately 900 kg (1 tn) of the pellets. The PAM-12 was applied using the same aerial application method as used for the seeding as shown in figure 6. The hopper was calibrated to air speed for applying 670 kg ha^{-1} (600 lb ac^{-1}) of the PAM-12 pellets. Based on the 1.2% PAM in the pellets, actual PAM application is calculated at 8 kg ha^{-1} (7 lb ac^{-1}).

Utah certified weed free agricultural wheat straw was purchased in 900 kg (1 tn) bales. The straw bales were loaded into large nets which were secured and tethered to the helicopter for aerial delivery at an application rate of 3,400 kg ha^{-1} (1.5 tn ac^{-1}) of straw mulch. The term "bale bombing" is sometimes used, which is an accurate phrase since the bombing technique is not very precise nor does it deliver an even layer of mulch to the ground.

Measuring Soil Hydrophobicity. Using an adaptation taken from the BAER Handbook (USDA 1995), soil hydrophobicity was tested every 3 m (10 ft) along a 30 m (100 ft) transect. Measurements were made at the soil surface, 3 cm (1 in) depth, and 5 cm (2 in) depth at each 3 m location. For the surface sample, any ash or litter was gently dusted off from the soil surface. Depth time-samples were taken by digging a shallow trench with a diagonal wall from the surface down to the desired depth exposing the subsurface soil at the bottom of the trench. Approximately 2 to 5 drops of water was applied to the top of the exposed soil surface. The time in seconds was recorded for how long water droplets remained on the soil surface.

Measuring Soil Movement. Soil movement over time was measured using an erosion bridge at each sample location (see figure 8). The erosion bridge consists of a 180 cm (72 in) masonry level that was placed on two 1 m (3 ft) long, 2 cm (0.75 in) diameter steel rebar support pins (Ranger et al. 1978). The pins were placed 170 cm (68 in) apart, 5 cm (2 in) in from each side of the level and driven into the ground using a small sledge. The two support pins are leveled at installation, and upon returning each year, the level is placed over the pins to ensure that they are still level prior to making measurements. Each bridge was placed parallel to the slope contour. A 2 m (6 ft) aluminum measuring stick was fastened on the top edge of the level to accommodate horizontal measurements. One end of the level had a reference hole that was always placed over the end of the most northern rebar.

The reference, or starting point, of the erosion bridge transect was always the northern most rebar. Soil surface changes were monitored by taking readings every inch (72 readings) along the top edge of the level as shown in figure 8. Measurements were always made on the downslope side of the level. Using an aluminum meter stick, readings were taken from the top edge of the level to the ground (or on top of litter/duff). Etched marks on the bottom edge of the level at 2.54 cm (1 in) intervals helped to

Figure 7

A commercially available polyacrylamide (PAM) product, PAM-12 Advanced Soil Technology (AST) manufactured by ENCAP, was used for all polyacrylamide soil treatments tested at the Red Bull Fire. PAM-12 pellets appear below, showing the size variation.

Figure 8

Use of the erosion bridge involved taking readings from the top edge to the ground surface on the downhill side and every inch along the level, using an aluminum meter-long measuring stick. Marks were etched on the bottom edge of the level at 2.54 cm intervals to ensure that the measuring stick was perpendicular.

ensure the measuring stick was perpendicular at each reading.

Measuring Vegetation Cover/Bare Ground. Ground cover readings were taken at 0.3 m (1 ft) intervals along a 30 m (100 ft) transect for 100 readings. The transect lines went along the hillslope contour, south from the end pin of the erosion bridge. At the point of intersection with the ground, the following readings were made: bare ground, rock (>2 cm [0.75 in] diameter), live vegetation, plant litter, and cryptobiotic crust.

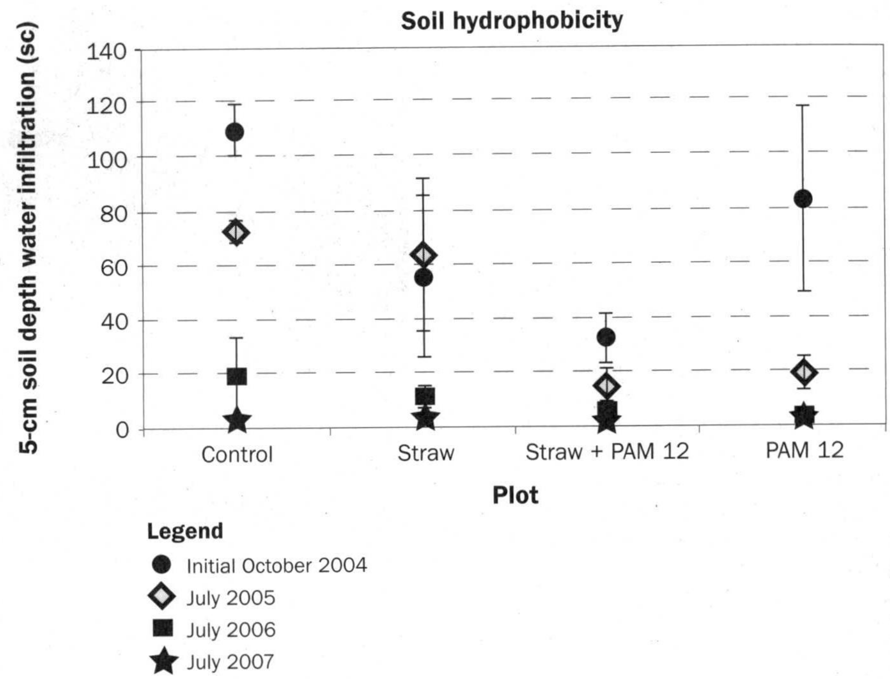
Results and Discussion

Data from the different measurements was statistically analyzed for differences in means using Coefficient of Variation (CV). Analysis of variance was used to determine treatment significance. Where CV error bars overlap, there is no significant difference; likewise, where CV error bars do not overlap, there were significant differences between treatments (figures 9, 11, 12).

Soil Type and Chemistry. The four treatment blocks are all situated in the same soil type, which meets the percent clay and divalent cation requirements for successful treatment with the PAM polymer. Soils within the soil map unit are classified as Typic Cryoboralfs, having formed in an ustic moisture zone and frigid temperature zone. The mapped A Horizon is 0 to 28 cm (0 to 11 in); has a texture of gravelly clay loam (30% clay, 25% gravel, and 10% cobble); many, very fine, interstitial pores; and a diagnostic subsurface argillic horizon. The colluvial soil is strongly calcareous lime with a pH of 8.2. Analysis of the post-fire soil on a "dry weight" basis shows divalent ionic species of 14.4 mmol kg^{-1} Ca^{2+} and 4.03 mmol kg^{-1} Mg^{2+} with an extract of soluble salts of 0.95 dS m^{-1}. Vegetation prior to the fire was mapped as Oak-brush, which is known to result in hydrophobic soil following wildfire. Slopes are concave having little rounding; elevation for the treatment blocks range from 2,200 to 2,400 m (7,200 ft to 7,800 ft) with a West aspect. Based on soil composition for texture and lime content, this soil should respond successfully to PAM treatment.

Soil Hydrophobicity. Figure 9 shows the results of soil hydrophobicity testing. Data are shown for water infiltration time in seconds at each treatment area during the BAER implementation prior to straw and PAM applications. As seen, there was a wide variation of readings at each site during initial conditions. However, there were significant differences between the control site versus the PAM site and the PAM + straw site because there is no overlap of the CV bars.

Figure 9
Water infiltration results for testing hydrophobic soil conditions. The graph shows initial water infiltration times during the Burn Area Emergency Rehabilitation implementation period prior to straw and polyacrylamide (PAM) applications. Significant differences are seen between the control site versus the PAM site and the PAM + straw. The results for the 2005 growing season show that the PAM treatments had the largest first-year drop in water infiltration time. There was a natural degradation of the water-repellent or hydrophobic soil conditions for all the treatments plots as seen for the 2006 and 2007 growing seasons. Both PAM treatments approach background levels in 2006, and all treatments approach background levels in 2007.



Note: Error bars represent a 90% confidence interval.

First year results were taken nine months following the treatment application. Fiscal year 2005 data shows that the PAM treatment had the largest first year drop in water infiltration time. Also, both PAM treatments have significantly lower infiltration times than either the control or the straw with mean infiltration times less than 20 seconds.

Data taken during the 2006 and 2007 growing seasons show a natural degradation of the water-repellent or hydrophobic soil conditions for all the treatment plots. Both PAM treatments approach background levels in 2006, and all treatments approach background levels in 2007. By the third year, all the study plots had the same water infiltration times.

The graph in figure 9 shows that PAM significantly decreased water infiltration time versus the control or straw treatment during the first growing season. The hydrophobic coating on the soil particles resulted in increased water infiltration time. It is possible that the PAM polymers at the molecular level are interacting in part with the hydrophobic coated clay particles, flocculating the soil and opening up interstitial channels, which allows for better water infiltration.

Hillslope Soil Movement. Soil erosion bridges were located midslope to measure soil loss and soil accumulation. Two approaches are used to compare the data. The first approach uses total soil movement as given by the absolute value of soil loss plus soil accumulation. The second approach uses the net difference between loss and accumulation, which is an estimate of soil erosion. The data is averaged for all three years of collection and is shown in figure 10.

Figure 10a shows the results for absolute soil movement. The difference in slope gradients between treatments was an unexpected variable that could confound results.

However, the PAM treatment was located on the steepest slopes, and the PAM + straw treatment was located on the slopes steeper than either the straw or the control treatments. The control was located on the shallowest slopes. Since both PAM treatments were located on the steeper slopes, the lowest levels of soil movement would be expected to occur on the straw and control sites. However, the data show both the PAM and PAM + straw treatments have significantly lower soil movement than either the control or the straw treatment.

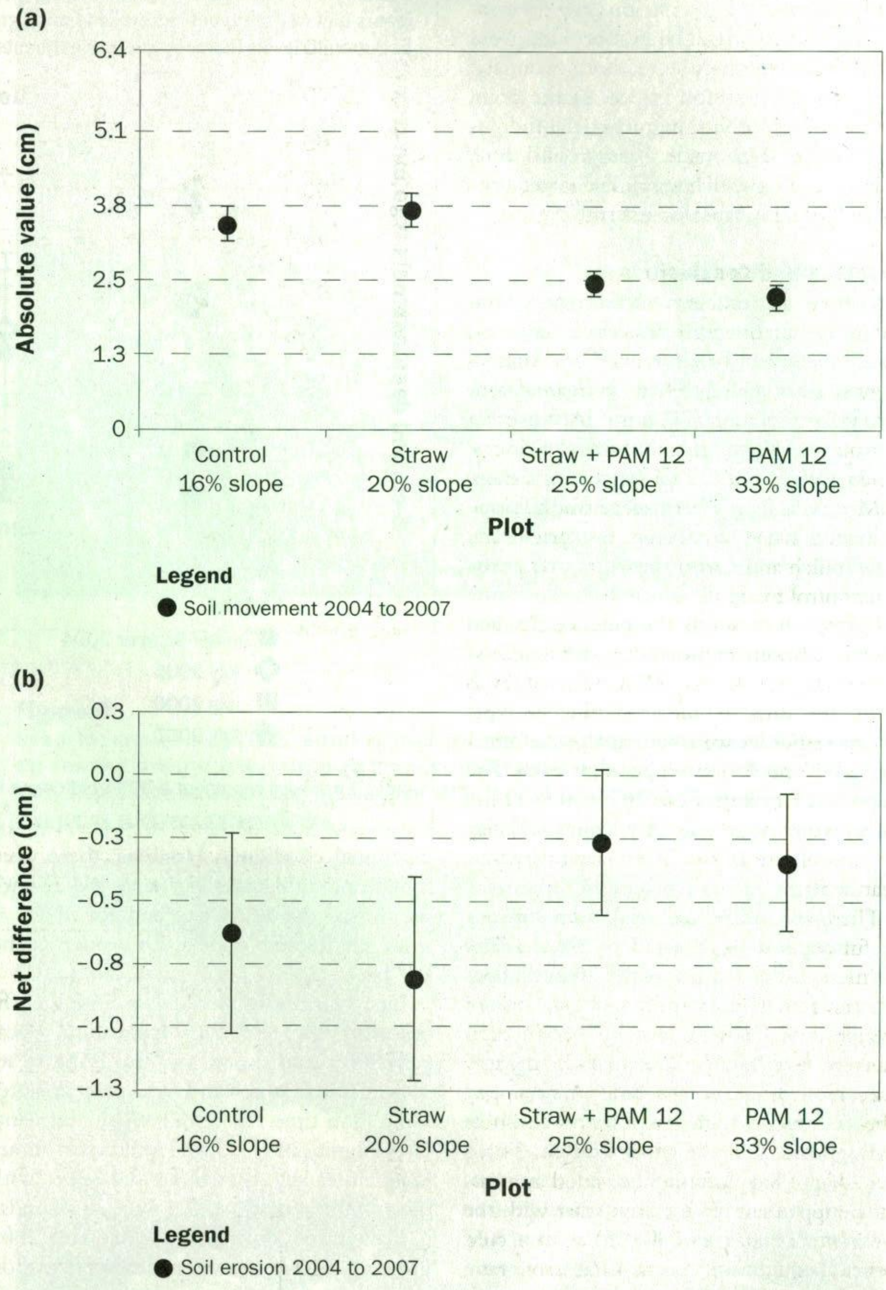
Figure 10b shows the results for net soil movement or soil erosion. As would be expected, this graph shows that all treatments lost soil over the three-year study. The graph shows that the PAM and PAM + straw have less mean soil loss than either the straw or the control treatments. Even though the mean differences are not significant, the PAM and PAM + straw were on the steepest slopes where erosion rates should have been the highest. The decreased soil movement and erosion are expected because the PAM polymer interacts with the clay fraction of the soil to enhance soil particle cohesion, thus mechanically reinforcing the soil's physical structure. The increased particle cohesion increases resistance to shear-induced particle detachment and helps flocculate the soil particles. A benefit of soil flocculation is increased water infiltration, which results in reduced soil erosion.

Vegetation Cover. Figure 11 shows the results of vegetation cover for the 2005 and 2006 growing season. The 2005 growing season shows that the PAM and PAM + straw treatments had higher percent basal vegetation cover than either the straw treatment or the control. The 2006 growing season shows that both PAM treatments had slightly higher mean values for vegetation cover, but differences were not significant except for the control versus the PAM-only treatment. Plant cover values merged during the 2007 growing season.

First year growth is critical for establishing initial vegetation cover and providing a source for next year seed and plant litter cover. The increased vegetation response to the PAM treatments is most likely the result of decreased seed eroding off the hillslope since there is a decrease in soil movement. Also, since water infiltration rates are increased with PAM treatments, soil moisture penetrates deeper into the soil profile, providing the necessary soil moisture for seedling and plant survival during the hot summer months when plants can become stressed from heat and dry weather conditions.

Figure 10

Absolute soil movement (a) and net soil movement/erosion (b) results. The polyacrylamide (PAM) treatments were located on the steeper slopes than either the straw or the control treatments. Both the PAM and PAM + straw treatments have significantly lower soil movement than either the control or the straw treatment. The PAM and PAM + straw have less mean soil loss than either the straw or the control treatments.



Note: Error bars represent a 95% confidence interval.

Bare Ground. Bare ground does not include rock (>2 cm [0.75 in] diameter), vegetation cover, litter, or cryptobiotic crust. Percent bare ground for the 2005 and 2006 growing seasons is shown in figure 12. For both growing seasons, the PAM and PAM + straw treatments both have significantly lower percent bare soil than either the straw treatment or the control. Again, the results merge for the 2007 growing season, and there are no significant differences for the percent bare ground.

With increased vegetation response as explained above, there should be a decrease in bare ground because of both increased plant cover and increased plant litter, especially in the later summer and fall months as grasses and forbs senesce and shrubs loose their leaves. Increased litter plus increased vegetation both translate into less bare ground.

Summary and Conclusions

It is essential to understand the interactions and processes between polyacrylamide and soil chemistry, soil texture, and soil mineralogy when applying PAM for treating soils following catastrophic wildfire. PAM is not a cure all for all soils or for all fire conditions. When applied under appropriate conditions, PAM treatment is a very successful hillslope treatment when compared to agricultural straw mulch and may outperform other erosion control treatments.

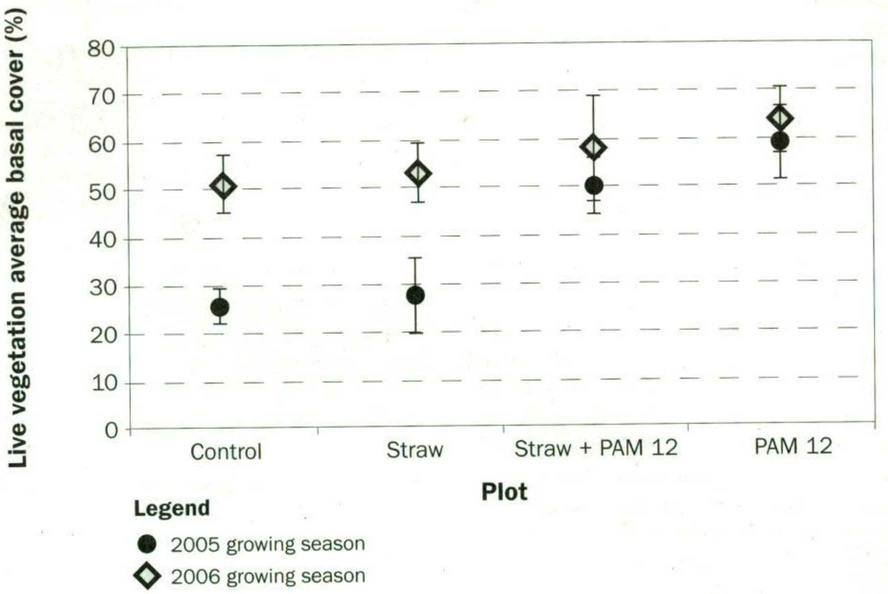
This study shows that fire induced hydrophobic soils were improved by applying PAM at the rate of 6 kg ha^{-1} (7 lb ac^{-1}) either as PAM or as PAM + straw. The first year vegetation responses were greatest for the PAM and the PAM + straw treatments. Although PAM treatments showed overall lower mean hillslope erosion, the differences are only significant relative to the control and the straw treatments.

There are several key soil factors for successful application of PAM treatments. The soil must have a high percentage of exchangeable clay minerals, approximately 30% clay or greater. Fine textured soils are good candidates for using PAM. These include silty clay loam, clay loam, silty clay, sandy clay, or clay. The soil must contain a source of soluble Ca^{2+} cations or some other divalent cation (e.g., Mg^{2+}). Gypsum can be added as a calcium supplement that will interact with the soil clay particles and the PAM molecule. Other studies have shown infiltration rates are reduced when PAM is applied to sandy soils; therefore, soils containing approximately 60% to 70% sand or greater, depending on soil texture, do not favorably respond to PAM treatment (Trout and Ajwa 2001; Ajwa and Trout 2006; Rough et al. 2004).

A better understanding of PAM chemistry in soils will allow for improved applications following wildfire. This paper presents

Figure 11

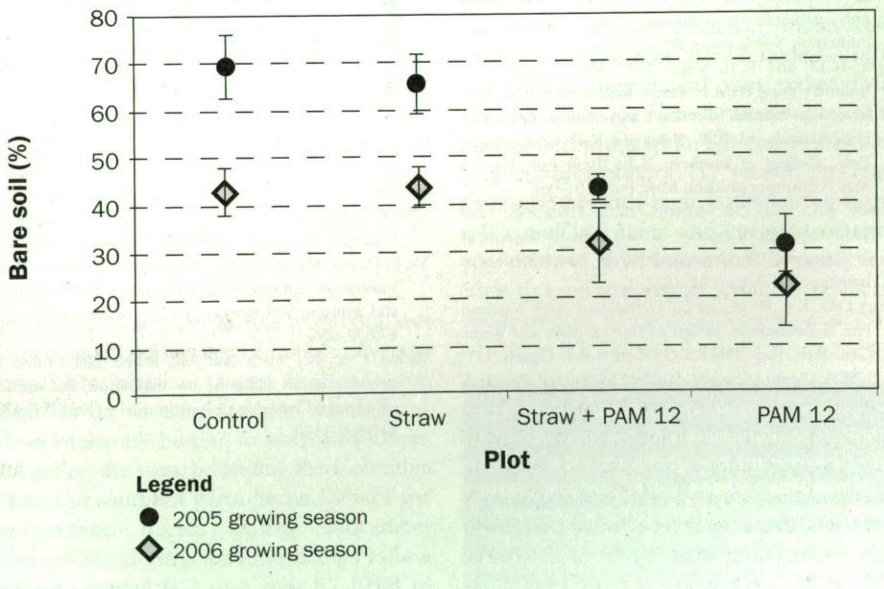
Results of vegetation cover for the 2005 and 2006 growing season. The polyacrylamide (PAM) and PAM + straw treatments had higher percent basal vegetation cover than either the straw treatment or the control during the 2005 growing season. The PAM treatment had significantly higher mean values for vegetation cover than the control during the 2006 growing season. Plant cover values merged during the 2007 growing season.



Note: Error bars represent a 90% confidence interval.

Figure 12

Percent bare ground for the 2005 and 2006 growing seasons. For both growing seasons, the polyacrylamide (PAM) and PAM + straw treatments both have significantly lower percent bare soil than either the straw treatment or the control. The results merge for the 2007 growing season, and there are no significant differences for the percent bare ground.



Note: Error bars represent a 90% confidence interval.

information from a screening study; therefore, further detailed work needs to be done. Other possible factors which could be evaluated include the effect of PAM concentration in fire-affected soil and the effect of adding ionic salts and PAM to hydrophobic sandy textured soils.

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